The Chicago Lake Breeze

Its Structure and Effect On Air Quality

Lucas Harris

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In cooperation with V. Rao Kotamarthi and the Environmental Research Division at Argonne National Laboratory

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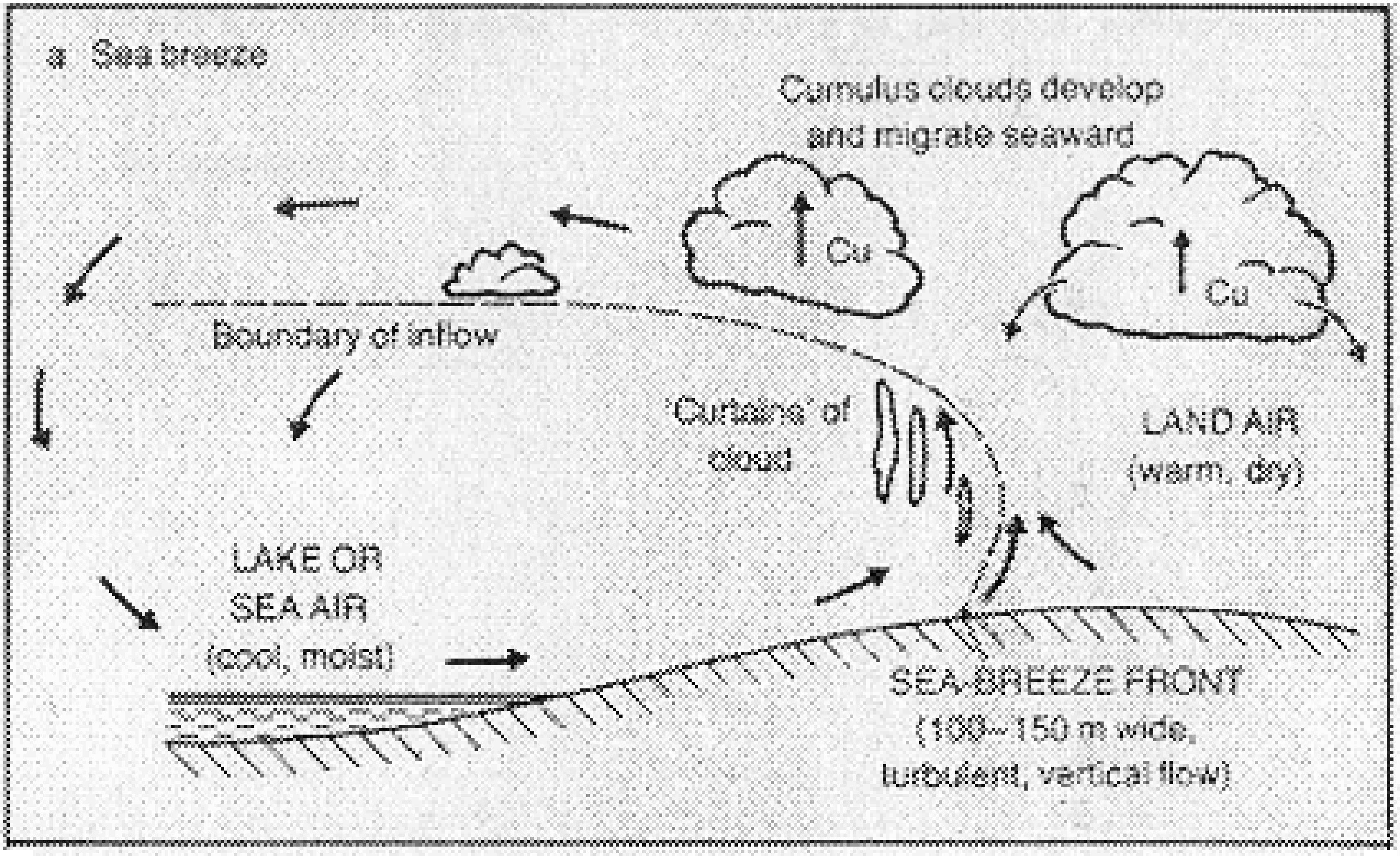
Lake (and Sea) Breezes



From *Weather Systems*, L.F. Musk, 1988, Cambridge Press

Lake (and Sea) Breezes

Lake breezes like:

- Clear days $\longrightarrow$ strong heating on land (specific heat) $\longrightarrow$ steep temperature gradient between land and water
- Weak synoptic forcing, a. k. a. high pressure
- Cool lake temps (temperature gradient again)

Lake (and Sea) Breezes

. . . and they can affect:

- Temperature — down!
- Wind Speed and Direction — light winds from the lake/sea
- Pressure (and vorticity)
- Humidity — up or down?
- Pollutant Dispersion

Lake breezes can also trigger thunderstorms, sometimes severe ones (several times this summer in Chicago)

Numerical Weather Prediction and Modeling

Discretize or "break" the continuous equations into individual bits in time and space

Requires attention to:

- Model resolution and numerical stability
- Subgrid-scale processes ("physics"— MAJOR source of problems)
- Verification with real data

NCAR/PSU MM5

Nonhydrostatic mesoscale model (meaning: capable of simulating phenomena smaller than 100 km with substantial vertical motion) developed at Penn State and the National Center for Atmospheric Research

- Free, open source, (somewhat) well documented
- Runs on just about any computer (even on Linux PCs)
- Very popular in government, academics (even NIU!), industry, forecasting (TWC "no humans required" forecasts)
- Used a lot in severe storms, winter weather, and air quality research
- Also used as an example in the frontiers of computer science (parallel/grid computing, data processing, visualization . . .)

Testing the Model

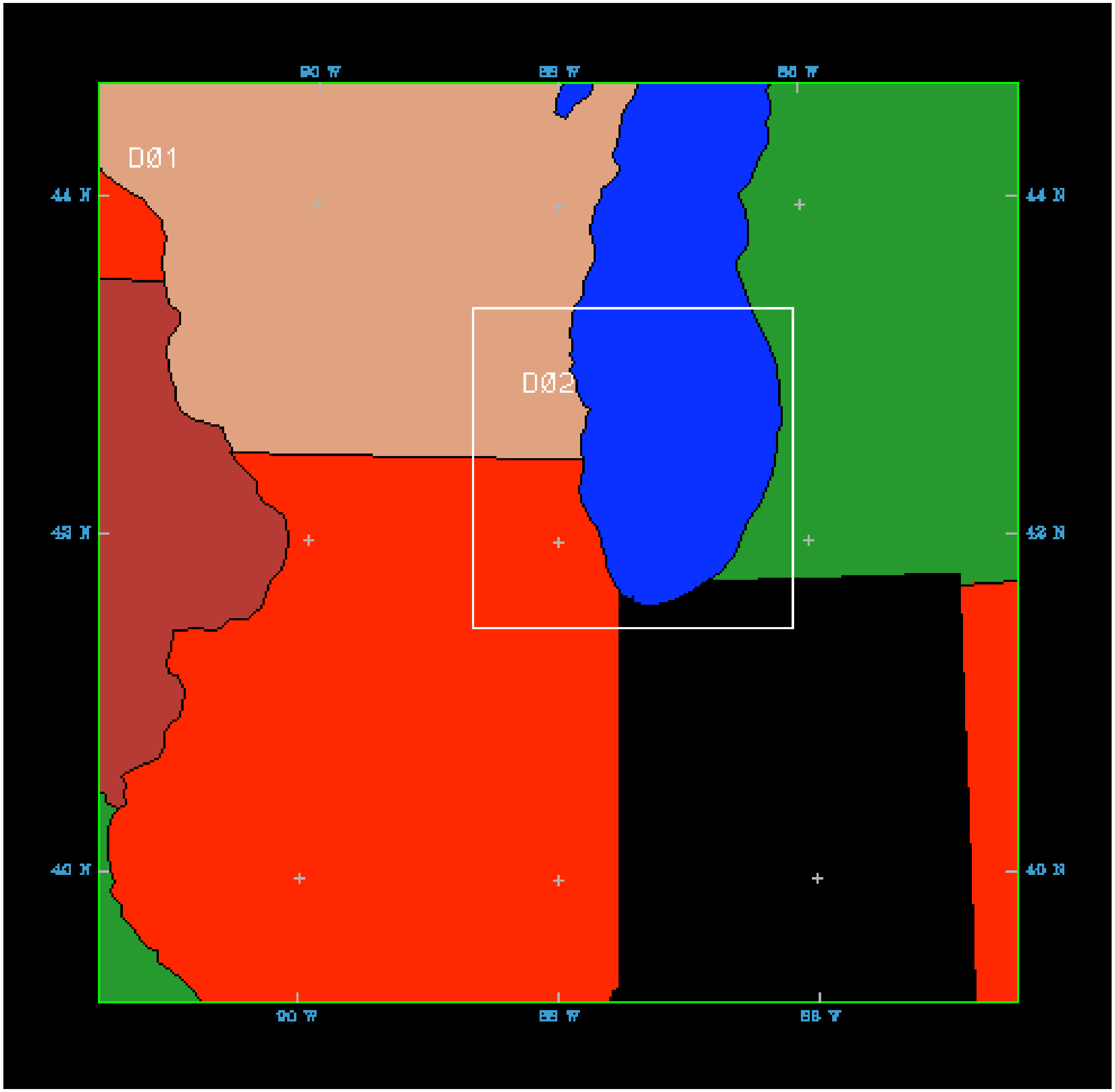
A test run was set up to determine a proper model configuration for capturing a lake breeze

- Calibrated with 7 July 1999 breeze event
  - Nested domains: an outer 50x50 grid with 12 km spacing and an inner 52x52 grid with 4 km spacing
  - 36 second timestep
  - NCAR Reanalysis data
  - 30s resolution topography (not that it matters in Illinois)
  - Run for 72 hours starting on the 6th to give the model some "warm up" time

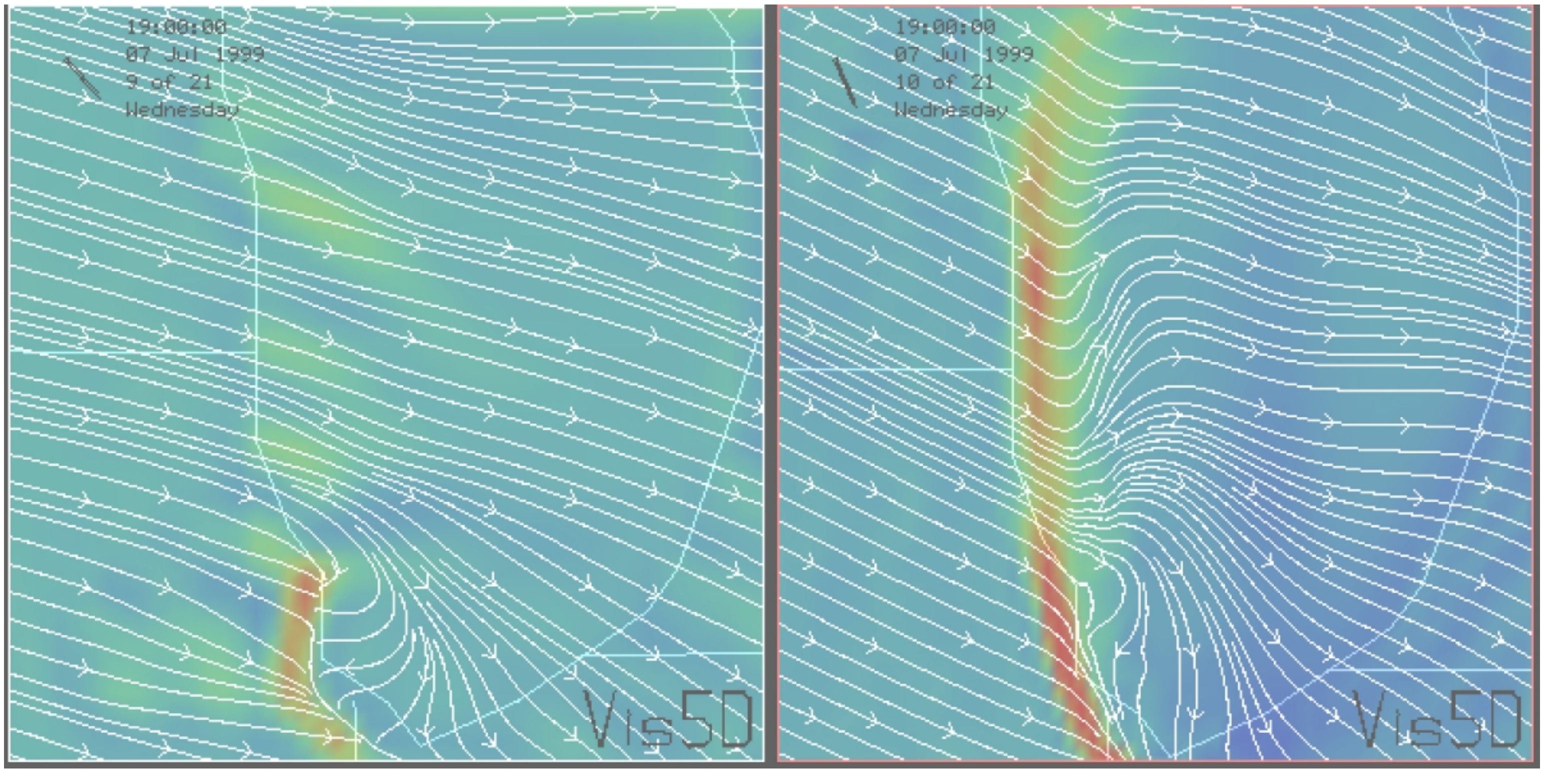
- Verification data from Argonne's tower at 10 and 60 meters

- MM5 vs. RAMS (CSU's competing model; a little flaky)

MM5 Model Domains



MM5 vs. RAMS



Near surface streamlines with 1000m vertical velocity (red is greatest upward)

Testing the Model: Results

Heights above model bottom
Errors for the 7th (midnight-midnight GMT) as seen at ANL
Wind direction deviations taken to be smallest angle between true and modeled directions

	MM5		RAMS	
10 m	Abs	RMSE	Abs	RMSE
Temp ($^\circ$C)	1.3	2.2	2.0	3.2
Wind Speed (m/s)	.9	1.5	.2	.4
Wind Direction ($^\circ$)	6.8	13.2	14.8	31.5
Pressure (mb)	.4	.7	3.7	5.7
Dew Point ($^\circ$C)	.9	1.8	2.2	3.4
60 m				
Temp ($^\circ$C)	1.0	1.7	1.6	2.6
Wind Speed (m/s)	.3	.6	.9	1.6
Wind Direction ($^\circ$)	6.8	13.8	16.7	34.9

MM5 seems to simulate the event with a higher degree of accuracy.

30 July 2002 Event

A lake breeze was detected on the afternoon of 30 July 2002 at Loyola University in Downtown Chicago

- Clear, warm day following a cloudy day
- Light southwest winds
- Somewhat muggy, dew points around 70°F

30 July 2002 Event

Goals for this simulation:

- Accurately simulate the breeze at ANL and Loyola
- Determine the effect the breeze has on pollution dispersion

This simulation was carried out using the same configuration as the 7 July 1999 run and the same dataset.

RAMS was not used here as it simply blew up during the run. . .

Verification

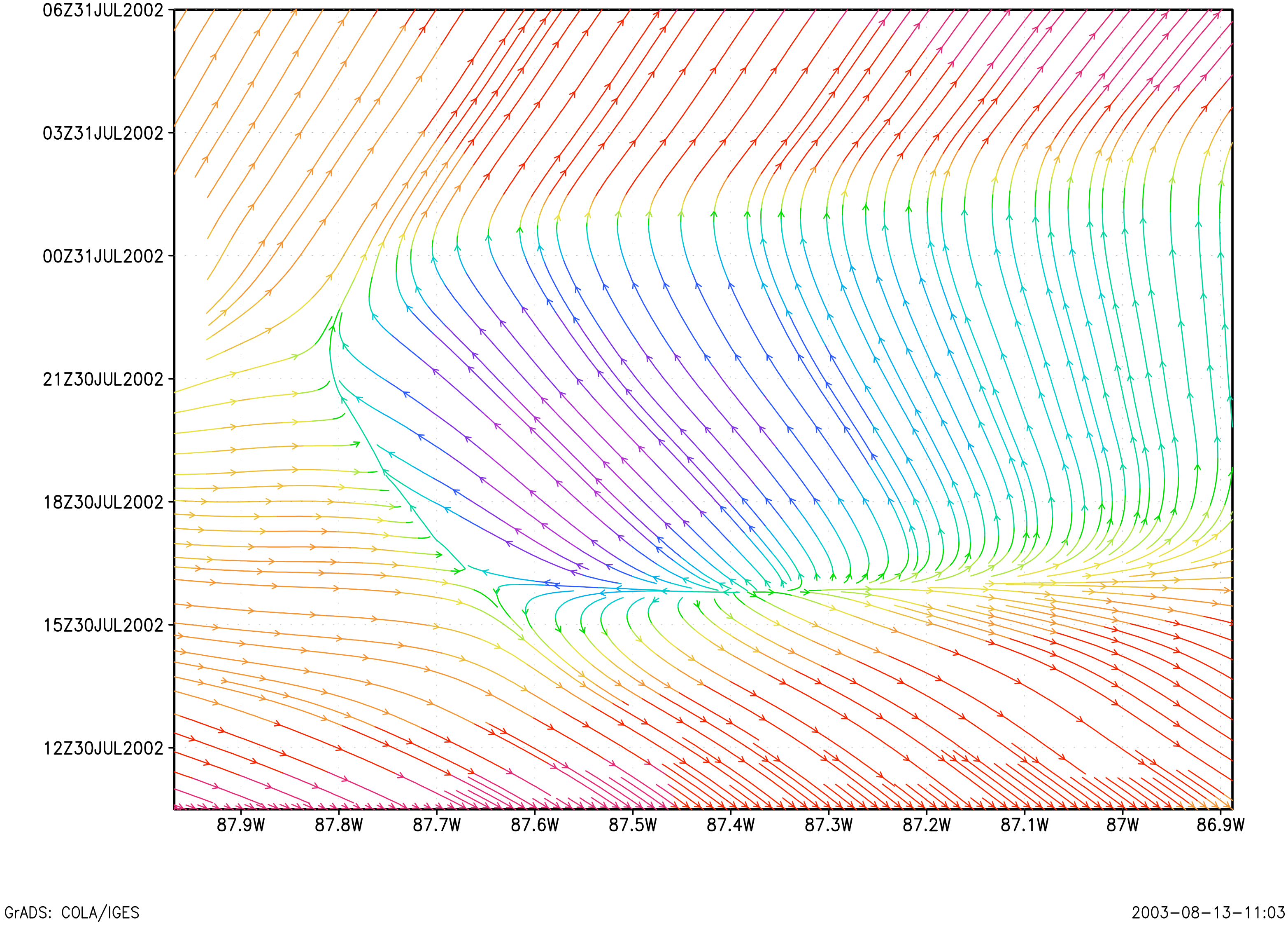
Same setup as before, on 30 July 2002

	Argonne		Loyola	
10 m	Abs	RMSE	Abs	RMSE
Temp (°C)	1.3	2.3	.8	1.8
Wind Speed (m/s)	.7	1.5	.4	1.1
Wind Direction (°)	5.6	10.5	—	—
Pressure (mb)	2.6	4.3	.73	1.5
Dew Point (°C)	.8	1.5	.4	1.0
60 m				
Temp (°C)	1.0	1.7	—	—
Wind Speed (m/s)	.3	.6	—	—
Wind Direction (°)	7.1	12.8	—	—

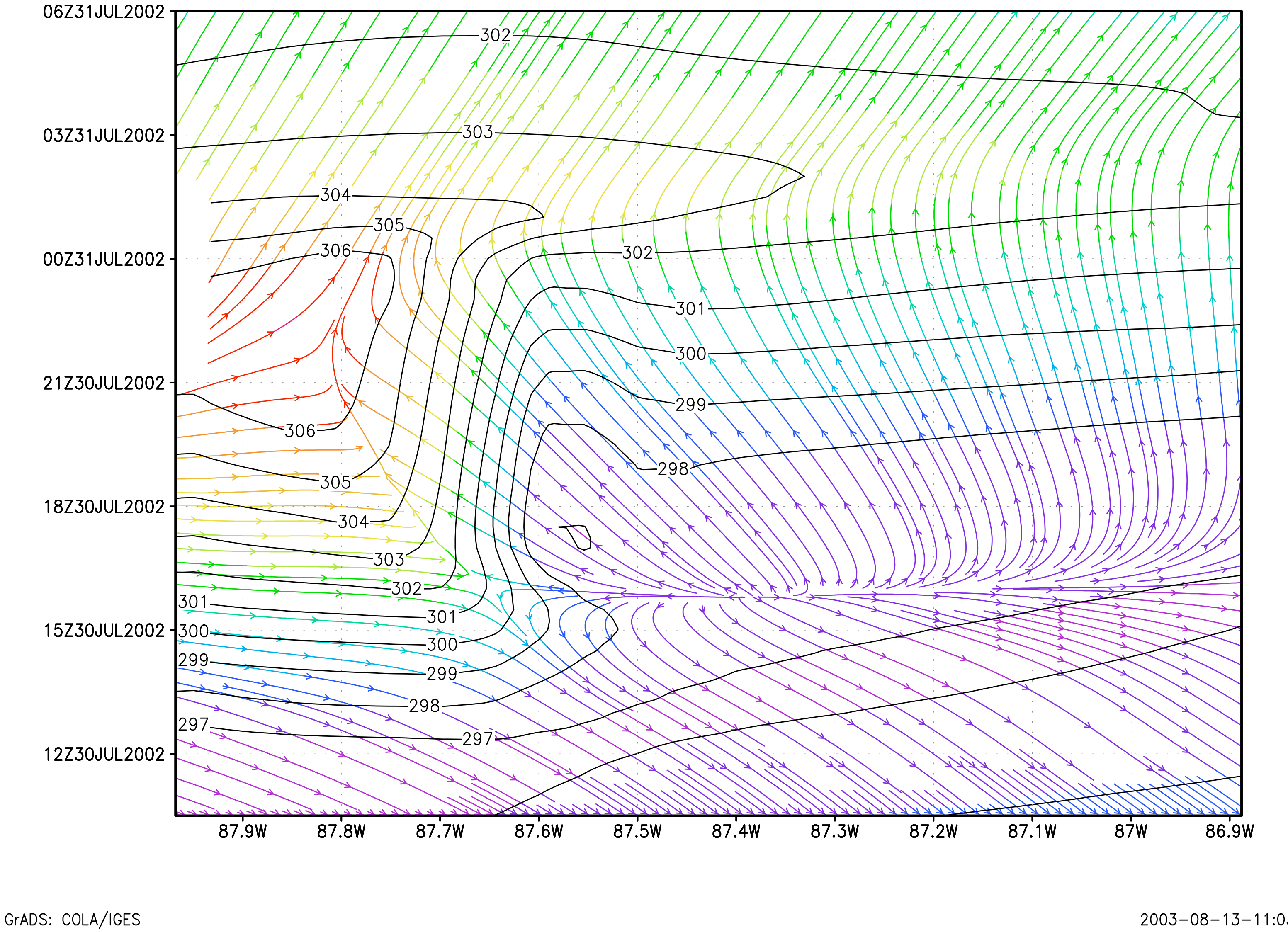
Breeze Effects

- A breeze circulation did spin up as expected
- Made it to Loyola at 11 am and left at 7 pm
- Extended 12 km inland with an inflow 600 m high
- Good temperature advection (up to $9°$C/hr for short periods), heavily dampening solar heating and stabilizing the atmosphere
- Humidity *increased* during the breeze
- Pressure increased slightly during the breeze onset

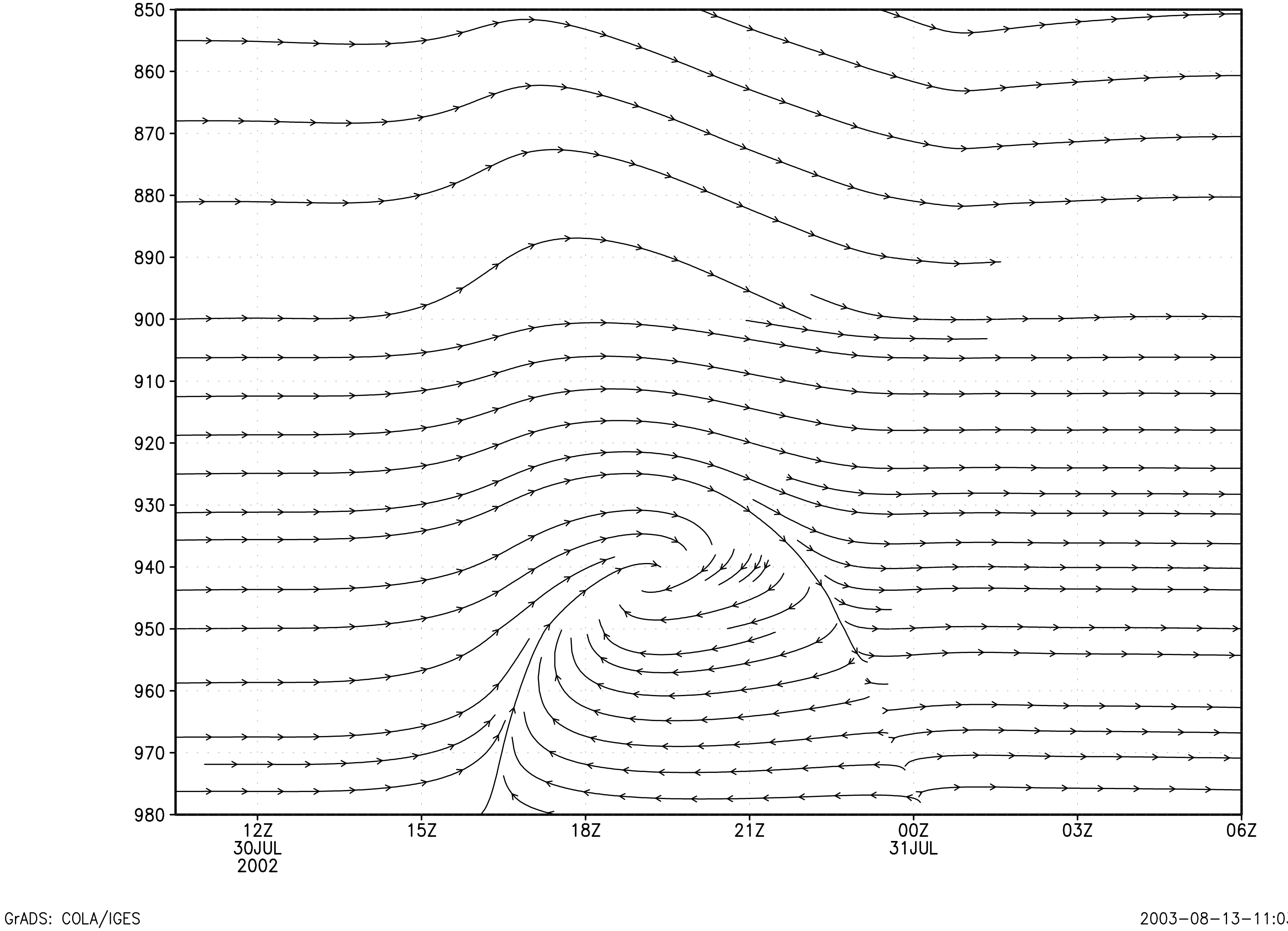
42° North horizontal streamlines in time



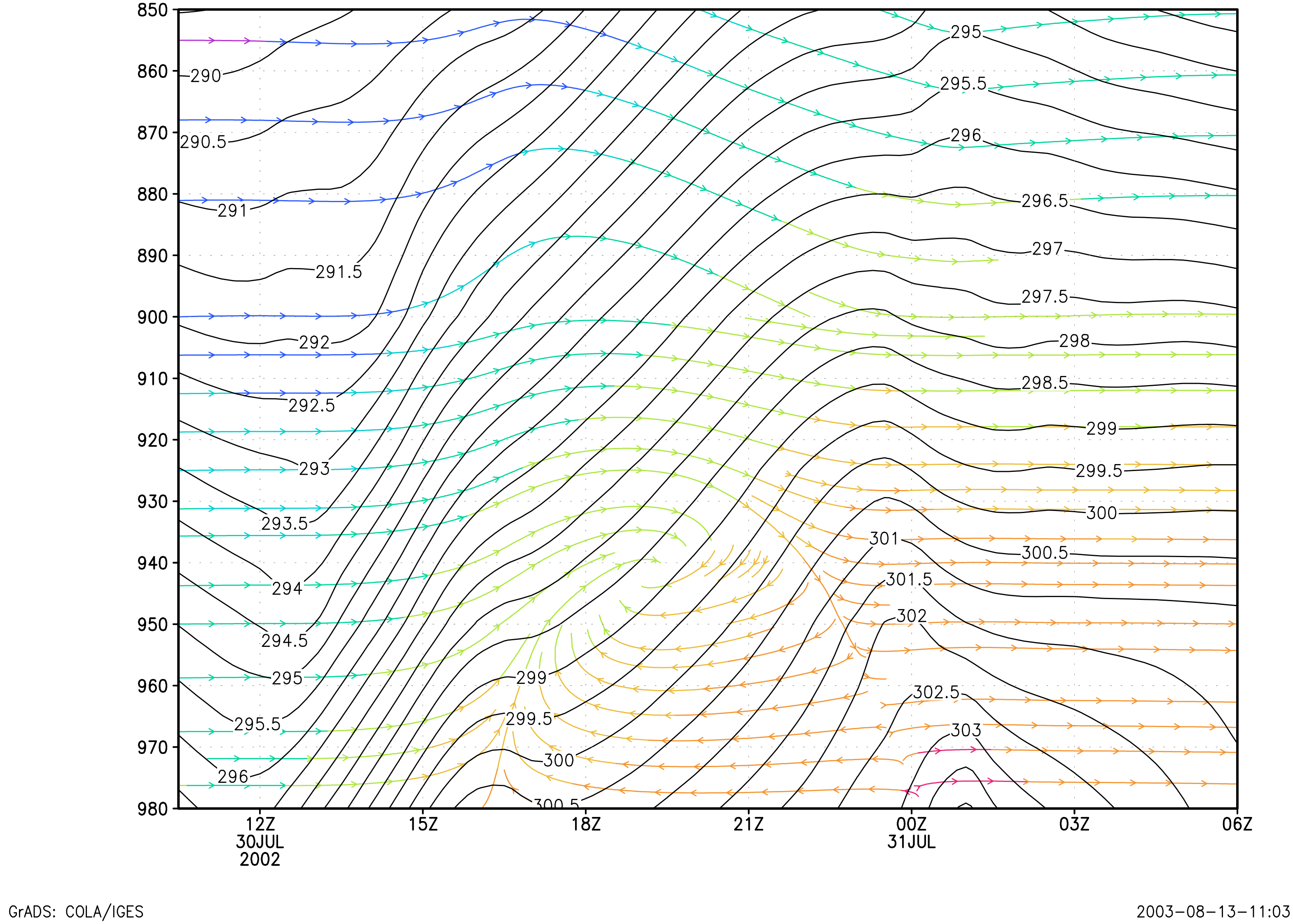
42° North horizontal temperatures in time



Loyola vertical streamlines in time



Loyola vertical temperatures in time



Trajectory Trapping

Letting a few imaginary particles out in the breeze

(animation)

The lake breeze tends to vent particles released before it sets up to the north (Milwaukee) and those released after it sets up to the northeast (Muskegon, MI)

Dispersion Model

Letting lots of imaginary particles in the breeze

(animation)

Possible Future Projects

- More events to simulate
- Development of a climatology
- Higher resolution/larger domain
- Sensitivity testing (changes in temperature, prevailing winds, etc.)
- Idealized Modeling
- More verification data (satellite, radar, upper air, chemical data, etc.)

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